STRATEGY FOR AN INTEGRATED ECOLOGICAL RESTORATION RESEARCH INITIATIVE

A Research Initiative Partnering EPA
with Other Federal and State Agencies
Interested in the Study, Evaluation and Restoration
of Riparian Buffer Areas
in the Mid-Atlantic Region

1.0 INTRODUCTION

Riparian buffer areas are areas of vegetation, (e.g., grasses, shrubs, trees, and other vegetation types, that are adjacent to bodies of water. Riparian buffer areas help maintain stream habitat diversity, channel morphology, food webs and biotic diversity; reduce sediment, phosphorus, and nitrogen loadings to streams and other water bodies; contribute to groundwater recharge and flood protection; and support the integrity of both aquatic and terrestrial ecosystems.

A sound scientific foundation exists to support the nutrient reduction and ecological values and functions of riparian buffers and to promote their use as an ecosystem management tool. (Bren 1993, NACD 1994, NRC 1992, USDA 1996). Nutrient enrichment presents a real threat for most bodies of water within the Mid-Atlantic Region. While many of the small streams (i.e., first through third order) in the Mid-Atlantic have baseflow total phosphorus concentrations that are below the EPA guideline of 100 ppb, about 20% of the stream miles in certain watersheds, such as the Susquehanna basin, have total phosphorus concentrations exceeding this phosphorus guideline. The Susquehanna basin is a major contributor of sediment and nutrients to Chesapeake Bay. In contrast to nutrients, about 25% of the stream miles in these smaller streams throughout the Mid-Atlantic Region have poor riparian habitat. An additional 50% of the stream miles in these streams have marginal riparian habitat with over 85% of the stream miles in the Susquehanna River Basin having poor or marginal riparian habitat.

Increased nutrients in Mid-Atlantic estuaries are an environmental problem. The Delaware Estuary exhibits some of the highest concentrations of nutrients measured anywhere in the world. The average concentration of phosphorous in Delaware coastal bays is twice that of the Maryland coastal system. In the Delmarva coastal bays system, concentrations of nutrients generally decrease southward, reflecting population and development trends. In the Chesapeake Bay, nitrogen levels are excessive in the upper bay and in most tributaries. While phosphorous concentrations in the Chesapeake Bay are lower than a few decades ago, most tributaries presently are still over-enriched.

One approach to reduce nutrient loadings, in effect now for certain areas of the Mid-Atlantic (i.e., Chesapeake Bay watershed), is the implementation of a Nutrient Reduction Strategy. Agriculture was identified as a major contributor of nutrients to the Chesapeake Bay in the 1987

Chesapeake Bay Agreement. Under this agreement, the states of Maryland, Pennsylvania, and Virginia, and the District of Columbia committed to a 40 percent nutrient load reduction to the Chesapeake Bay by the year 2000. These jurisdictions have made the implementation of agricultural nonpoint source pollution control programs a priority.

Nutrient management is a pollution prevention practice that manages the rate, timing, and method of application of nutrients and minimizes their potential losses through runoff or leaching to groundwater. Nitrogen, phosphorus, and potassium are three essential plant nutrients used in significant amounts in intensive agricultural operations. These nutrients are important for satisfactory crop production but, if not managed properly, can easily move from farmland to ground and surface waters. Nutrient management received new emphasis in the mid-1980's as an important management practice to supplement ongoing soil conservation and water quality plans and animal waste best management practices. Although the Nutrient Management Program is administered by different agencies in each state, the programs are well established and coordinated at the local level, based on individual state needs and available technical support.

Riparian buffer areas have been proposed, and are being evaluated, as a nutrient management method. However, the exact requirements for these riparian areas, such as size of buffer area, species composition, interaction between surface and groundwater, and many other crucial factors are incompletely understood. In addition, other functions of riparian buffer areas (e.g., stream flow regulation, instream habitat, sediment transport reduction, and maintenance of biotic integrity) must be evaluated along with nutrient management.

Many of the existing and proposed riparian buffer area programs focus on a specific water body, stream reach or local problem area. However, the effects and impacts of riparian areas can transfer beyond the local site. Restoring riparian buffer areas upstream in a watershed can contribute to improved conditions downstream, reducing the cumulative impacts of watershed land use activities on downstream river, lake, and estuarine systems. Interactions between riparian buffer areas and aquatic ecosystems at the local, watershed, and basin scales, however, are not well understood.

2.0 GOAL AND OBJECTIVES

2.1 GOAL

The goal of this initiative is to better understand the interactions and relationships between riparian buffer areas and aquatic systems at different spatial and temporal scales, develop predictive tools, formulate strategies and guidance for managing ecological resources at these scales, and communicate the strategies and guidance through alliance groups.

2.2 OBJECTIVES

The goal of this initiative can be achieved if five objectives are satisfied.

1) **Objective 1:** Characterize riparian areas and associated watershed and landscape attributes (e.g. riparian area width, length, vegetative structure, watershed land use/land cover areas, landscape connectivity, etc.) to better understand the relationships among these attributes at different spatial scales and target selected riparian areas for study and restoration.
2) **Objective 2:** Investigate a variety of riparian area configurations in a variety of landscape settings to understand how riparian buffer areas function and develop predictive tools for estimating how restoration efforts would support water quality, biodiversity, and other ecosystem management objectives.
3) **Objective 3:** Develop design guidance for restoring and implementing riparian buffer areas on the landscape at the watershed level.
4) **Objective 4:** Evaluate the effectiveness and performance of these riparian buffer configurations through remote sensing and ground-level monitoring.
5) **Objective 5:** Demonstrate the efficiency of federal and state agency alliances in conducting environmental research on crucial management issues.

This brief paper outlines an approach for an integrated ecological restoration research initiative to study, evaluate, restore, and manage riparian buffers areas in the Mid-Atlantic region (Figure 1).

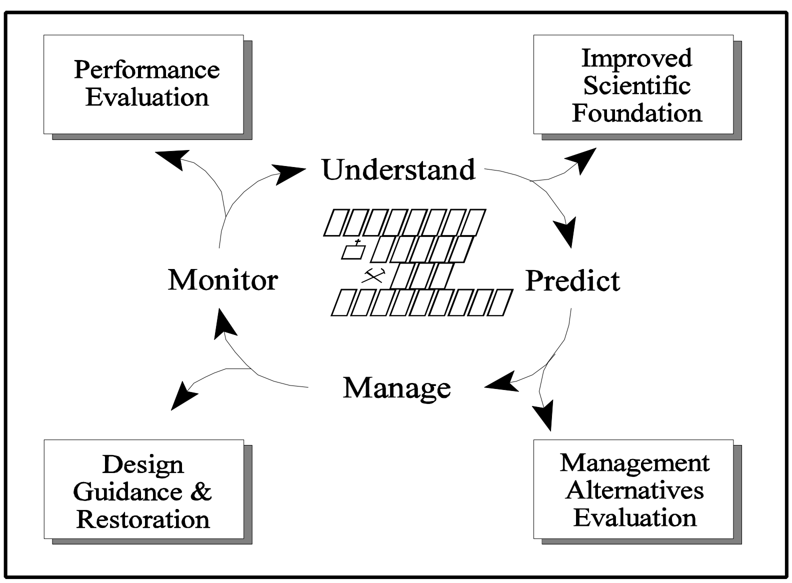

Figure 1. General objectives and products for the Riparian Buffer Area Initiative.

3.0 STRATEGIC ELEMENTS

The following elements are proposed to satisfy the goals and objectives of the integrated ecological restoration research program. These elements are, of course, interrelated and other elements may need to be added to fulfill unforeseen requirements.

3.1 Alliance Formation

At the present time, the following members of the alliance proposed for this research project are:

- US Environmental Protection Agency (Region III, Chesapeake Bay Program, and Office of Research and Development)
- US Department of Agriculture (Agricultural Research Service, Forest Service, and Natural Resources Conservation Service)
- US Geologic Survey (Water Resources Division and Biological Resources Division)
- US Army Corps of Engineers

In addition, the states of Maryland, Delaware, Pennsylvania, Virginia and West Virginia Departments of Agriculture and Natural Resources will probably be most interested.

3.1.1 Innovative Partnerships

This ecological restoration research initiative is possible because of several unique partnerships which have already been formed within the Mid-Atlantic region. The Mid-Atlantic Assessment Team located in Annapolis, MD, was created as a joint venture between the EPA Office of Research and Development and EPA Region III. One of the major objectives of the Team is to create partnerships with other Federal, State and Local agencies in the conduct of ecological research and assessments. The team has successfully accomplished this goal by creating partnerships through formal and informal arrangements with most of the Federal and State agencies with responsibilities for environmental issues in the Mid-Atlantic area.

The second major commitment that recently occurred is the partnership formed among the three major research laboratories within the US Environmental Protection Agency. The ecological components of the National Health and Ecological Effects Research Laboratory (NHEERL), the National Exposure Research Laboratory (NERL) and the National Risk Management Research Laboratory (NRMRL)—all of the Office of Research and Development— have agreed to join together to focus their considerable research capabilities on environmental restoration problems in the Mid-Atlantic area.

Each organizational unit brings their discrete expertise to bear upon this approach to ecological restoration research. The NHEERL has responsibility for the Environmental

Monitoring and Assessment Program, which is a research program focused on estimating the condition of ecological resources. The NERL has responsibility for chemical and other stressor research, including a substantial landscape characterization and ecology research program. The NRMRL has responsibility for ecological restoration research.

A formidable research capability therefore emerges when the above EPA components are joined with the research capacities of other Federal and State agencies.

3.1.2 Cooperative Research Alliance

Several significant research and restoration projects are being planned and/or conducted within the Mid-Atlantic Region. To mention a few, the Chesapeake Bay Program has established several subcommittees that are exploring aspects of habitat and riparian forest buffer restoration. The US Department of Agriculture has expanded their Conservation Reserve Program to promote conservation efforts in the Chesapeake Bay watershed. States within the watershed are eligible to develop enhanced conservation programs in partnership with the USDA and to share the costs of additional incentive programs aimed at addressing regional conservation priorities. The EPA Office of Research and Development has indicated a substantial interest in riparian forest buffer restoration research, as described above. Considering these programs and others which have not been identified here, it seems prudent to attempt to determine areas where cooperative research alliances would be beneficial to all participants.

3.2 Research Framework

3.2.1 Research Questions

There are five general questions driving this research initiative in the Mid-Atlantic Region:

1) What are the characteristics of existing riparian buffer areas and surrounding landscape areas?
2) How do riparian areas function?
3) Where should we put riparian areas on the landscape?
4) How do we restore riparian buffer areas?
5) How effective is the restoration?

Typically, providing answers to general questions means additional, more detailed questions must be addressed first. These additional questions can be arranged in a hierarchical order, based on the increased level of detail (Table 1). The information needed to answer these hierarchical questions will guide the design of research studies. Identifying the appropriate questions will be an on-going effort throughout the initiative.

Trade-offs are an important consideration in any environmental research and management program. There are different risks associated with different activities. For example, reducing nutrient runoff in surface waters can increase nutrient concentrations (particularly nitrate) in groundwater through infiltration; decreasing sediment input to streams can increase stream bed scour; providing additional corridors for wildlife movement can increase the incidence of Lyme disease and other animal diseases transmissible to humans. The risks associated with different outcomes, however, are not equal. Being able to evaluate and assess the risks associated with different management alternatives has become a critical part of environmental management. Therefore, this initiative will use the EPA Ecological Risk Assessment Framework (EPA 1992, 1996) to help guide the initiative (Figure 2). The Ecological Risk Assessment Framework provides a systematic, but flexible, approach for formulating the problem, identifying appropriate analysis procedures, and, ultimately, characterizing and comparing the risks associated with different management alternatives.

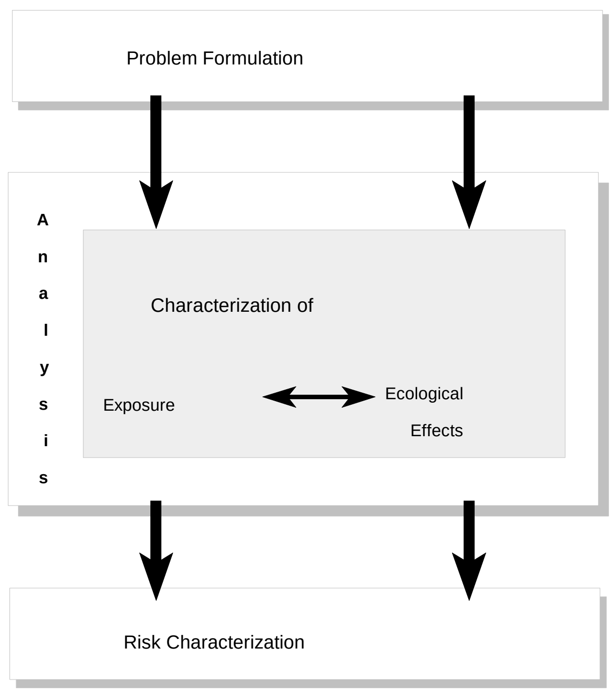

Figure 2. Ecological Risk Assessment Framework. Ecological risk assessment is a way of determining the likelihood of adverse ecological effects from a variety of stressors or management practices.

3.2.2 Restoration Research

To move this Initiative forward, a research plan will be developed, which would include all phases of the restoration program to achieve the goal and objectives stated in Chapter 2.0. The plan would be subject to scientific peer review to ensure the proposed research is scientifically sound. Research would be conducted in four general areas: targeting and characterizing riparian buffer areas, riparian buffer area configurations, confirmation monitoring, and evaluation tools.

3.2.2.1 Targeting/Characterization

Riparian buffer areas are the areas of vegetation between the terrestrial watershed and the aquatic systems, especially riverine and lacustrine systems. Processes occurring within these ecotones and the terrestrial-water resources interactions will be the organizing foci of this initiative and help to focus this study on riparian buffer areas. Concurrence on a method of selecting areas for study and restoration will be one of the initial activities.

One approach is to organize the substantial databases that have been established by each of the partner agencies. For example, the EPA Environmental Monitoring and Assessment Program (EMAP) has sampled over 400 streams in the Mid-Atlantic Region, selected using a statistical sampling survey design, measuring a variety of physical, chemical, and biological indicators, including indicators of riparian habitat. The Maryland Biological Stream Survey also has sampled streams selected using a statistical sampling survey design throughout Maryland. Data also are available from USDA FS and NRCS, USGS, and FWS programs, the Chesapeake Bay Program, other state agencies, and universities throughout the Region. The location of riparian buffer areas in these databases can be identified in the GIS system that the EPA EMAP Landscape Ecology program has established for all the watersheds in the Mid-Atlantic Region. The landscape attributes (e.g. road density, land use, etc.) for each of the watersheds has been determined using satellite imagery and aerial photography. The characteristics of the watershed and landscape around each of the riparian buffer areas being studied by the partner agencies will be determined at a variety of geographic scales - local site, watershed, ecoregion, or basin.

Following the characterization of each of the partner agency sites and the identification of other candidate sites as part of the targeting activities, selection criteria will be developed for selecting study sites. It is proposed that two tiers or categories of sites be selected: intensively studied sites and extensively monitored sites. This approach would permit the collection of detailed information on the structure and function of riparian buffer areas while also obtaining more information on the characteristics of a large number of riparian buffer areas in the Mid-Atlantic. Identifying the selection criteria and selecting these sites will be a critical activity in the research program. A two tiered approach for studying riparian systems is needed because it is unlikely there will be sufficient resources to intensively study multiple sites. For example, assume that representative riparian areas would be selected from three major strata: hydrologic type (streams, lakes, estuaries), land use (agriculture, forest, urban/suburban), and geomorphic setting (coastal plain, non-coastal plain). Selection of one riparian buffer area from each of the possible combinations from these three major strata, with no replication, would result in a minimum of 18 intensive research sites. These intensive research sites will not represent all the sites of interest (e.g., small streams, larger rivers, different ecoregions, reservoirs, coastal bay tributaries, etc.). Including both intensive and extensively studied sites should provide information to assist in transferring information from the intensive research sites to other sites in the region. In addition, issues related to local, watershed, and regional scales can be better addressed with data from both intensive and extensively studied sites.

Equally important in the restoration of these areas is the restoration of the terrestrial and aquatic biota, the native plants and animals of the area, and historic wetland areas in these riparian areas. Restoration of the native plants and animals has become a goal of many states and individuals interested in restoring riparian areas. Not only is it assumed that the restoration of native plants and animals are the sign of a healthy community, but there is the additional aesthetic benefit realized when these areas are used as hiking and nature trails or as community park settings.

3.2.2.2 Riparian Buffer Area Configurations

Nutrient and sediment reduction within riparian buffer areas has been demonstrated (Altman and Parizek 1994, Bingham et al. 1980, Danick and Gilliam 1996, Lowrance et al. 1984). However, there is considerable uncertainty surrounding the configuration of riparian areas and the effectiveness and efficiency of pollutant removal at all scales. This research will focus on identifying the areal size (minimum linear distances away from and along the stream), species composition (e.g., use of native versus nonnative species), flow path (e.g., surface-subsurface transport interactions, soil moisture, recharge), removal processes (e.g., uptake versus physical adsorption or sequestering), with the emphasis on landscape positioning or the landscape locations needed to attain various pollutant removal efficiencies. The research, however, will also focus on the configurations required to improve the downstream habitat by contributing woody debris, root wads, and other sources of allochthonocus material to support stream biota.

Configuration research efforts will build on existing research being conducted by partner agencies. The emphasis of this research will be on larger scale issues such as positioning of different riparian area configurations on the landscape and the reduction in downstream cumulative impacts. This research will be integrated with the monitoring research being conducted in the Mid-Atlantic.

3.2.2.3 Configuration Monitoring

A tiered monitoring network will be implemented following the concept proposed by the CENR Monitoring Committee with high frequency intensive monitoring (e.g., individual storm sampling) at selected riparian research sites; lower frequency (e.g., semi-annual or annual), but more extensive, monitoring throughout the region; and remote sensing using satellite imagery and aerial photography.

High intensity monitoring will provide information on the effectiveness and efficiency of different riparian area configurations on nutrient and sediment removal, surface and groundwater flow paths, and organic matter transport and loading.

Low frequency, spatially extensive monitoring will provide information on the current status and changes in riparian area and aquatic system condition for different riparian area configurations in different watersheds, ecoregions, and basins as a function of stream order, lake or coastal bay area, riparian area size, species composition, and other similar factors.

This monitoring effort also will include ecotone indicators such as game bird, songbird, and shorebird community metrics; amphibian indicators; and selected wildlife species. Selected HEP indicators will be incorporated in the monitoring network. The remote sensing monitoring will provide information on the current status and changes in landscape characteristics such as the area and proportion of land use/land cover in the watershed (e.g., crop type, clear cutting, urban development), habitat fragmentation, riparian area-forest area connectivity, and other landscape indicators.

The monitoring information will be integrated with the configuration research results to formulate and improve evaluation tools for predicting riparian area responses to different management activities within the watershed.

3.2.2.4 Evaluation Tools

To evaluate alternative management strategies, both empirical and process models are useful. The local scale process-oriented models will be formulated based on the site-specific research being conducted by other agencies. Riparian area and wetland models (e.g., EPRI 1997) are being developed and can be tested and refined based on information from these sites. Different evaluation tools, however, are needed to address management strategies at watershed and basin scales.

The information to be collected through the extensive monitoring network is appropriate for formulating empirical and landscape models. Empirical models such as lake eutrophication models, revised universal soil loss equations, and estuarine benthic index models require cross-sectional data or data collected from a variety of different sites and environmental conditions. These empirical models will be formulated to include parameters and variables that contribute to the design of riparian buffer areas and the evaluation of alternative management strategies.

Similar empirical landscape models will be formulated using landscape metrics (e.g., % agricultural area upstream, fractal indices, connectivity) that are associated with various riparian and stream community metrics (songbird diversity, HEP community structure index, IBI or SBII metrics, cumulative impact metrics). One of the objectives of this initiative is to evaluate the importance of landscape positioning of riparian buffer areas on improving downstream aquatic systems. These landscape models will provide a tool for evaluating alternative landscape designs.

An additional objective is to provide information for restoring and managing riparian buffer areas to improve and protect aquatic systems.

3.2.3 Management

Three sub-elements are proposed to assist managers and decision makers in restoring riparian buffer areas: design guidance, performance assessments, and economic cost/benefit procedures.

3.2.3.1 Design Guidance

The purpose of the design guidance will be to contribute to watershed management and protection programs by incorporating riparian buffer areas into these programs. Design guidance for construction of riparian buffer areas is being developed by the USDA NRCS, FS, US Army Corps of Engineers, and other partner agencies. The design guidance from this initiative would complement the guidance from these other agencies, but focus on watershed and landscape placement of riparian areas to enhance the cumulative effectiveness of riparian areas within the basin. The guidance will also incorporate information on riparian area width, species composition and configuration, and other site specific attributes with watershed characteristics such as land use/land cover, critical sediment/nutrient transport areas, wildlife migration corridors, the downstream receiving systems, ecoregional characteristics, restoration goals and objectives, and risk reduction criteria for the watershed and basin. Design guidance will be embedded within a watershed management context.

3.2.3.2 Performance Assessment

An important part of the initiative will be to demonstrate the effectiveness and performance of riparian buffer areas in improving both terrestrial and aquatic ecosystems. For example, results from this initiative contribute directly to EPA Offices of Water and Research and Development GPRA objectives to: 1) restore and protect watersheds; 2) develop tools to reduce loadings and improve water quality; 3) provide state-of-the-science measurements, methods, and models to assess ecological risks; and 4) provide the scientific understanding to measure, model, maintain, or restore, at multiple scales, the integrity and sustainability of ecosystems now and in the future. Throughout the initiative, various products and tools will be provided to address these GPRA objectives, including the conduct of periodic ecological risk assessments so the overall performance of riparian buffer areas on achieving risk reduction goals can be evaluated. An initial assessment will be conducted within the first 1 to 2 years of the initiative to establish a baseline for future comparisons. Subsequent assessments will be compared with this baseline. Baseline risks will be revised, as needed, if continued research and monitoring information indicates that these initial risk estimates were incorrect. Post restoration audit studies also will be performed to determine if the “as-built” riparian ecosystems are consistent with the design guidance.

3.2.3.3 Economic Documentation

The economic value of ecological goods and services typically is not considered in many environmental projects. Consequently, subsequent estimates of economic benefits from the restoration effort are difficult to determine. The EPA ORD Science To Achieve Results (STAR) Grants Program has emphasized interdisciplinary research over the past several years, including integrated socioeconomic elements. NSF and the EPA STAR program have funded several interdisciplinary projects to formulate procedures for estimating the costs and benefits of ecological services. Some of these procedures include improved elicitation approaches, willingness to sacrifice, and alternative incentive level surveys. These procedures will be evaluated and tested as part of this initiative. Including economic indicators at the initiation of a research project does not guarantee that the costs and benefits will be estimated at the conclusion of the research project, but it significantly increases the probability that appropriate economic indicators, costs, and benefits will be considered as part of the research.

Multiuse riparian areas can provide direct economic benefits. For example, orchards might be planted along with native grasses as part of the riparian buffer area. Fruit or nuts from the orchard trees could be harvested as a cash crop. Purdue University horticulturists, wildlife specialists, and agronomists have teamed to plant ornamental bushes such as pussy willow, red-twigged dogwood, and corkscrew willow in riparian areas. These ornamentals also represent a cash crop because the branches can be harvested and used in floral displays. In addition, this harvesting can occur in the dormant fall or winter period with minimal impact on riparian vegetation. Proper pruning or harvesting of the branches also results in a greater density of branches, which provides habitat and understory for game birds and other wildlife species. These and other ideas will be pursued to provide direct economic benefits and incentives for farmers, homeowners or other land owners to plant and maintain riparian buffer areas.

4.0 ONE APPLICATION: RELEVANCE TO HUMAN HEALTH AND ECOLOGICAL EFFECTS

Restoring and enhancing riparian buffer areas around bodies of water in the Mid-Atlantic area should have a direct bearing on nutrient flux into these waters, and thus contribute to a reduction in the risk factors associated with outbreaks of Pfiesteria-like dinoflagellates. Nutrient enrichment appears to have some unknown association with risk of Pfiesteria outbreaks. An expert scientific panel created by the Governor of Maryland to study the Pfiesteria problem in the Chesapeake Bay has concluded that reducing nutrients should reduce the risk of future Pfiesteria outbreaks. Areas of consensus by this scientific panel included:

- Nutrients concentrations in Eastern Shore tidal rivers are high relative to other rivers with similar salinity.
- Nutrient concentrations in lower portions of these tidal rivers and in the Rappahannock River have increased over the last 12 years.

- Record precipitation and runoff during 1996 and early 1997 resulted in increased nutrients to Lower Eastern Shore rivers.
- In laboratory cultures, the growth of nontoxic stages of *Pfiesteria piscicida* can be stimulated by the addition of nutrients.
- Nutrients stimulate the growth of algae and other microbes on which Pfiesteria-like dinoflagellates can grow.
- Pfiesteria-like dinoflagellates are abundant in areas with high concentrations of algae and microbes.
- At this point, it cannot be determined which nutrient (nitrogen or phosphorous) is more important in stimulating the growth of Pfiesteria-like dinoflagellates.
- High nutrient concentrations are not required for Pfiesteria-like dinoflagellates to transform into toxic stages.
- Populations of Pfiesteria-like dinoflagellates may also be controlled by predators and pathogens, but this has not yet been demonstrated.
- It is improbable that toxic contaminants, such as pesticides and trace metals, are primarily responsible for outbreaks of Pfiesteria-like dinoflagellates.

Restoration of riparian buffer areas and proper positioning of these areas within the Chesapeake Bay watershed could reduce nutrient transport and concentrations to the Bay, subsequently reducing the risk of Pfiesteria outbreaks. Other management applications for this type of riparian buffer restoration research are also present in the Mid-Atlantic area.

5.0 REFERENCES

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Table 1. Examples of the research and management questions guiding the Riparian Buffer Zone Initiative.

1. What are the characteristics of existing riparian buffer areas and surrounding landscape areas?

a. What is the distribution of riparian areas in the Mid-Atlantic?

1) *What is the average width of riparian areas associated with different stream orders? lake shoreline? coastal bay shorelines?*
2) *What proportion of stream miles (by stream order), lake shoreline, and coastal bay shoreline have riparian buffer areas at least 30 m in width?*

b. What is the vegetative and faunal composition of these riparian areas?

1) *What plant species are associated with these riparian areas?*
2) *What is the configuration or association of plant species in these areas?*
3) *What is the diversity of songbird communities in these areas?*

c. What are the characteristics of the watershed land use/land cover upstream of the riparian areas?

1) *What proportion of the watershed is in agriculture? silviculture? urban/suburban?*
2) *What are the characteristics of riparian areas associated with agricultural watersheds? forested watersheds? timbered watersheds? urban/suburban areas?*

d. What are the characteristics of the stream, lake, or coastal bay systems downstream from these riparian areas?

1) *What are the characteristics of the stream substrate upstream and downstream from riparian areas?*
2) *What are the suspended sediment concentrations associated with various riparian areas and land use?*
3) *What are the nutrient concentrations associated with various riparian areas and land use?*

e. What are the characteristics of the animal communities associated with riparian areas?

1) *What is the distribution and abundance of the benthic community species upstream and downstream from various riparian areas?*
2) *What fish species and community structure are associated with riparian areas?*

Table 1. Continued.

3) *What is the composition of songbirds, raptors, or other bird species?*
4) *What game and non-game wildlife species are found in these riparian areas?*

2. How do riparian areas function?

a. What is the influence of riparian areas on hydrology?

1) *How does the above ground biomass affect surface water runoff?*
2) *Do different plant communities affect water retention and groundwater recharge in riparian areas?*
3) *What is the interaction between surface and subsurface flow in riparian areas?*

b. How do riparian areas affect nutrient transport?

1) *What is the effect of different plant growth strategies (e.g., r vs k selected species) on nutrient removal?*
2) *Does the organic matter and leaf litter build-up encourage better water and nutrient retention?*

c. How do riparian areas affect sediment transport?

1) *What are the trap efficiencies of different riparian boundaries?*
2) *What is the range of erosional loads that can be processed by different riparian buffer areas?*

d. What are the interactions among the upstream watershed land use, the riparian area, and the downstream aquatic system?

1) *What are the associations among watershed land use areas, riparian buffer area configurations, and stream quality?*
2) *What are the cumulative effects of multiple riparian areas and basin stream quality?*

e. How do riparian areas contribute to faunal diversity?

1) *Which vegetative species and patterns contribute to increased faunal diversity?*
2) *How do faunal species contribute to sustaining riparian areas?*
3) *How wide should riparian areas be to provide migration corridors for wildlife species?*

Table 1. Continued.

3. Where should we put riparian areas on the landscape?

a. What are the relationships between watershed land use and area and riparian area width and composition?

   1) How do zoned riparian areas function under different types of land use?
   2) What is the relationship between the intensity of land use, area of land use, and riparian area width and composition?

b. What is the relationship between the type and quantity of riparian buffer areas on smaller first through third order streams and downstream riverine sediment/nutrient loads to lakes and estuaries?

   1) What benefits accrue to downstream river quality from riparian areas on first order streams?
   2) How effective are riparian areas when the location is more than 10 km upstream?

4. How do we restore riparian buffer areas?

a. What engineering specifications are required for different flow, soil, and sediment regimes?
b. What riparian buffer area dimensions and vegetative configurations are required to achieve the designs criteria?
c. What predictive tools are needed to evaluate different management strategies?

5. How effective is the restoration?

a. Which variables should be monitored to assess the performance of the restoration efforts?
b. How frequently should the monitoring occur?
c. What are the trade-offs in risks associated with riparian area restoration?